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# A stochastic model designed to estimate variability in the relative economic value between cattle with and without lung lesions in U.S. feedlot production systems

**Jason S. Nickell**, DVM, PhD, DACVPM
Global Manager Veterinary Services – Beef Cattle, Bayer Animal Health, P.O. Box 390, Shawnee, KS 66201, (913) 268-2081, jason.nickell@bayer.com

## Abstract

Feedlot cattle with lung lesions, associated with bovine respiratory disease (BRD), display a reduction in average daily gain (ADG) compared to cattle without lung lesions. However, a moderate degree of variability in prevalence and ADG reduction has been observed in peer-reviewed literature; therefore, the true economic impact of lung lesions in feedlot cattle populations is unknown. The study objective was to estimate and compare the relative economic value between feedlot cattle with and without lung lesions through stochastic modeling methods.

The model commenced at animal purchase and upon pen placement. Within each pen, cattle with and without lung lesions were modeled in parallel throughout the feeding phase, incorporating all production expenses and revenue. The final outcome was the difference in economic value between both cohorts when marketed on a live-weight basis.

Based upon the assumption of this model, cattle with lung lesions lose, on average, $38.69 (90% probability interval: $12.28 to $79.32) compared to cattle without lung lesions. The reduction in ADG among cattle with lung lesions was a major driver in these outcomes supporting the findings from prior studies. Improved BRD diagnostic and therapeutic modalities are necessary to reduce lung lesion prevalence and subsequent negative economic impacts to the feedlot industry.

**Key words:** feedlot, bovine respiratory disease, BRD, lung lesions, average daily gain, ADG

## Résumé

Les bovins en parc d'engraissement présentant des lésions pulmonaires associées au complexe respiratoire bovine (CRB) présentent un gain moyen quotidien (GMQ) plus faible que les bovins exempts de ces lésions. Toutefois, une variabilité modérée dans la prévalence et dans la diminution de GMQ a été observée dans la littérature scientifique; par conséquent, l'impact économique réel des lésions pulmonaires chez les bovins en parc d'engraissement n'est pas connu. Le but de cette étude était d'évaluer et de comparer la valeur économique relative des bovins en parc d'engraissement avec et sans lésions pulmonaires à l'aide de méthodes de modélisation stochastique. Le modèle était appliqué dès l'achat de l'animal jusqu'à sa mise en enclos. Les bovins avec et sans lésions pulmonaires étaient modélisés en parallèle par enclos durant la phase d'engraissement, en incluant l'ensemble des dépenses et des revenus de production. Le résultat final représentait la différence de la valeur économique entre les deux groupes sur une base de poids vif. Basé sur l'hypothèse de ce modèle, un bovin présentant des lésions pulmonaires représente une perte moyenne de $38.69 (90% intervalle de probabilité : $12.28 à $79.32) comparativement à celui exempt de lésions pulmonaires. La baisse de GMQ chez les bovins avec lésions pulmonaires était un facteur déterminant dans ces résultats ce qui correspond avec les conclusions d'études précédentes. L'amélioration du diagnostic et des modalités thérapeutiques du CRB sont nécessaires pour diminuer la prévalence des lésions pulmonaires et les impacts économiques négatifs subséquents dans l'industrie des parcs d'engraissement.

## Introduction

The bovine pulmonary system, like that of other mammalian species, is continuously exposed to a wide array of pathogens whose effects are generally insignificant due to effective clearance by the innate pulmonary defenses. However, if these defenses are overwhelmed by the pathogen (alone or in combination with pre-existing risk factors) respiratory disease is likely to ensue. Bovine respiratory disease (BRD) is the primary infectious disease syndrome encountered in feedlot production systems.[20,21,34,38,39,43] The high incidence of BRD in the feedlot phase of beef production is driven by synergism among respiratory pathogens and multiple risk factors for disease, such as age, immune status, commingling, and duration of travel.[4,12,13,41] Consequently, BRD has repeatedly been shown to adversely affect the value of cattle by increasing treatment costs, increasing mortality risk, loss of feed performance, lighter finish weights, and a decline in desirable carcass characteristics.

The bovine lung is highly susceptible to disease compared to other mammalian species. Cattle possess a small lung field relative to their body mass.[48] However, the proportion of tracheal volume to total lung volume is similar to that of the horse, indicating that the lower respiratory system of the bovine is at greater risk of exposure to inspired air and its contaminants.[48] If disease manifests within the bovine lung, collateral ventilation is highly limited and subsequently increases the risk of atelectasis and decreased gas exchange in diseased lung fields.[1] In addition, it has also been suggested that blood flow to the ventral aspect of the bovine lung is reduced compared to the dorsal half, thereby minimizing the activity of pulmonary macrophages in the region of the lung at greatest risk of disease.[48] These anatomic and physiologic elements of the bovine respiratory system decrease the ability of cattle to adapt to a reduction in ventilation when lung consolidation is induced by BRD. This creates a scenario in which cattle are very sensitive to the loss of functional lung tissue.

Historically, veterinarians and producers have utilized multiple tools such as antimicrobials, vaccines, and various ancillary therapies in an attempt to manage the negative effects of BRD.[6,18,19,31,32,40,54] Despite the efficacy afforded by these preventive and therapeutic modalities, the incidence of BRD in the feedlot phase of production has failed to be significantly reduced over time.[28] Possibly even more significant is the inability to accurately diagnose BRD among populations of afflicted cattle.[53] Prior studies have observed high proportions of cattle possessing lung lesions at slaughter.[8,21,34,35,43] Cattle with lesions were among cohorts that both received and failed to receive therapy during the feedlot phase of production.[8,21,43]

The finding of lung lesions among cattle without history of BRD treatment suggests that current BRD diagnostic regimens lack the robustness necessary to accurately identify morbid animals. Conversely, the identification of cattle with lesions at slaughter and with a history of antimicrobial treatment suggest that the therapies employed were either administered too late in the disease process, thereby confirming the inferiority of current diagnostic methods, or lacked sufficient efficacy to completely mitigate lung pathology. Nonetheless, the presence of lung lesions at slaughter among cattle has consistently been associated with a reduction in average daily gain (ADG) when compared to cattle without evidence of lung lesions.[8,21,34,35,43,56] Cattle with lung lesions at slaughter have also been retrospectively shown to be at greater risk of having received previous BRD treatment in the feedlot compared to cattle without lung lesions.[8,10,21,34,38,43]

Stochastic modeling is a tool that combines deterministic (i.e. static) decision processes with the concept of probability. Multiple factors that introduce the probability of occurrence into any process can provide a more robust estimate of the target scenario. Assuming that adequate data are available, and/or conservative estimates can reliably be generated with the data at hand, stochastic modeling studies are advantageous as they integrate existing data to describe probability, and the degree of variability within those distributions, within the realm of the research question. The external validity of these findings is contingent upon the assumptions and parameters built into the model and the reality of the distributions employed therein. Therefore, like all other research, researchers and practicing veterinarians must be mindful of these issues and determine if the model assumptions reflect the management practices of their clientele prior to extrapolating these findings to their own research or day-to-day caseload.

Given the quantity of data describing the detrimental effect of lung lesions on performance, it is not difficult to conclude that the development of lung pathology negatively impacts feedlot performance. However, due to the degree of variability in reported performance outcomes, it is advantageous to estimate the distribution of economic effect in feedlot production. The objective of this study was to utilize stochastic modeling to estimate the financial impact that the presence of lung lesions may have on the profitability of feedlot cattle.

## Materials and Methods

The current stochastic model was constructed to evaluate a pen of feedlot cattle based upon the assumptions described below. The model estimates reflect the production and economic factors that exist from the point of purchase of the cattle to the point of sale on a live-weight basis. The outcome parameter was defined as the difference in the relative economic value between cattle with lung lesions and cattle without lung lesions.

*Model structure*

The model was generated in a node format subsequently categorizing the analysis into sections. As discussed above, cattle in this model were evaluated on the pen level; pen capacity was modeled based upon typical US feedlot pen sizes (Table 1).[4,55,57] Prevalence of cattle with lung lesions was then estimated in order to split the pen into 2 cohorts, the number of cattle with and without lung lesions.[8,9,21,30,34,35,38,43,56] Therefore, Node 1 culminated in the estimation of the number of calves with and without lung lesions within each modeled pen. The remainder of the model then followed these 2 cohorts to finish.

Node 2 was focused on estimating the overall cost of feeding cattle in each of the 2 cohorts. The average purchase weight was assumed to be the same for both cohorts (Table 1).[45,50,57] The market price was based upon contemporary calf prices (accessed on 31 March, 2016) for feeder steers while incorporating a \$0.05 price slide (Table 1).[14] Within each simulated pen of cattle, the projected number of days spent in the feedlot was determined by the average purchase

**Table 1.** Distributions of model parameters implemented to estimate the relative value of cattle with and without lung lesions in the feedlot.

| Node | Parameter | Distribution | Truncated values* | Divisional factor | References |
|---|---|---|---|---|---|
| 1 | Feedlot pen size | Pert (20, 150, 500) | (20, 500) | NA | 9,26,27 |
| 1 | Prevalence of calves with lung lesions | Beta (6.273, 41.2) | 2.5th to 97.5th percentile (95% probability interval) | 1000 | 3-6,22-24,28,29 |
| 2 | Purchase weight of feeder calves (lb) | Pert† (277, 675, 1038) | (277, 1038) | NA | 27,30,31 |
| 2 | Purchase price ($/cwt)‡ | Pert ($138.37,$152.05,$165.73) | ($138.37, $165.73) | NA | 32,41 |
| 2 | Projected ADG (lb) | Pert (1.80, 3.30, 5.41) | (1.80, 5.41) | NA | 27,31 |
| 2 | Projected finish weight (lb) | Normal (1250, 77) | (904, 1547) | NA | 27,31 |
| 2 | Feed cost (DM basis) ($/ton) | Pert ($220, $290, $350) | ($200, $350) | NA | 27,31 |
| 2 | Interest rate on the capital necessary to purchase calves | Pert (3%, 6%, 8%) | (3%, 8%) | NA | 33 |
| 2 | Freight distance to feedlot (miles) | Pert (0, 470, 1930) | (0, 1930) | NA | 7,8,34-36,38 |
| 2 | Freight cost ($/mile) | Uniform ($3.50, $4.00) | NA | NA | 33 |
| 2 | Mortality (%) | Beta General (183.208, 13266.619) | (0%, 27%) | 1000 | 9,42,44,59 |
| 2 | Processing costs at arrival ($/hd) | Pert ($5, $15, $20) | ($5, $20) | NA | 33 |
| 2 | Morbidity among cattle without lung lesions | Beta (39.1, 229.38) | NA | 100 | 3-6,23,28 |
| 2 | Increase in morbidity risk among cattle with lung lesions | Beta General (0.577, 2.475) | (0%, 65%) | 1000 | 3-6,23,28 |
| 2 | BRD treatment cost ($/sick calf) | Pert (0.42, 8.32, 16.01)§ | (0.42, 16.01) | NA | Bayer Animal Health internal market data |
| 2 | Dry-matter intake (lb/hd/day) | Pert (8.7, 19.3, 29.3) | (8.7, 29.3) | NA | 60 |
| 2 | ADG among cattle without lung lesions (lb/day) | Pert (2.4, 3.08, 3.48) | (2.4, 3.48) | NA | 3,5,22-24 |
| 2 | Loss of ADG among cattle with lung lesions (compared with cattle without lung lesions) (lb/day) | Pert (0.05, 0.2, 0.4) | (0.05, 0.4) | NA | 3-5,22-24 |
| 3 | Expected market price of fed cattle ($/lb) | Pert ($1.08, $1.19, $1.30) | ($1.08, $1.30) | NA | 40,41 |

*Truncated values indicate that a minimum and maximum value have been placed on the potential outcomes generated by the respective distribution. A failure to truncate a distribution may lead to nonsensical outcomes.

†A Pert distribution is comprised of 3 values: a minimum value, a most-likely value, and a maximum value. It is subsequently displayed in the following manner: Pert (min, most-likely, max).

‡Market price displayed reflects 750 lb feeder calf price only. However, the feeder calf weight and market price are correlated in the model. A $0.05 price slide was built into the model.

§Distribution and truncated values shown in this table reflect BRD treatment costs for a 500 lb calf only. However, in the model, separate distributions were generated for numerous weight classes categorized in 100 lb increments (400 lb – 1000 lb). Therefore, in the model, this value was dependent upon the average purchase weight of the pen of calves entering the feedyard.

weight,[45,50,57] the projected ADG,[57] and the projected finish weight[50,57] (Table 1). Calculation of interest rate, freight distance, and freight cost per mile was then estimated for both cohorts (Table 1). These costs were assumed to be the same regardless of cohort; therefore, the reader is advised that these parameters have minimal effect on the model, but were added for descriptive purposes only.

Node 2 then ensued to calculate health costs between the 2 cohorts. Processing costs, BRD morbidity among cattle without lung lesions at slaughter, probability of additional BRD morbidity observed among cattle with lung lesions at slaughter, BRD mortality, and the cost of BRD treatment were determined (Table 1).

Node 2 concluded by calculating ancillary costs (e.g., yardage costs;[a] Table 1, Table 4) and feed costs. Feed costs were further broken out by calculation of dry-matter intake, ADG among calves without lung lesions at slaughter, and loss of ADG among cattle with lung lesions at slaughter (Table 1).

The overall cost assessment in Node 2 was calculated by the summation of non-feed costs (interest rate of purchase capital, freight costs, death loss, BRD treatment costs, beef check-off costs, yardage costs, operating interest, processing costs at arrival) and feed costs (Table 1).[a,12,16,22,25,34,36,37,52]

Node 3 estimated the fed cattle market price (accessed on 31 March, 2016) for both cohorts.[15] Gross revenue (minus dead calves) and total cost of gain (COG) were calculated at the individual calf level. The final output for the model consisted of determining the difference in net income per head between cattle with and without lung lesions. A replica of the model is displayed in Table 2.

*Data collection*

A controlled and focused literature search was performed on 16 March, 2016 to identify data pertinent to the current research question. Specifically, the ultimate goal of this literature search was to identify publications that reported associations between lung lesions and ADG estimates within US feedlot production systems. The utilized databases, along with the search terms, recorded timeframes of publication, and the number of results were as follows: Pubmed ("Cattle"[Mesh] AND "Lung"[Mesh], AND "Feedlot"; any date; 55 results), Agricola ("Cattle" AND "Lung" AND "Feedlot"; all dates; 20 results), American Association of Bovine Practitioners (*The Bovine Practitioner*) ("Cattle" AND "Lung" AND "Feedlot"; all dates; 60 results), and Academy of Veterinary Consultants (meeting proceedings) ("Cattle" AND "Lung" AND "Feedlot"; all dates; 190 results). Each article title and abstract was individually evaluated to assess its relevance to the scope of the model. Articles with titles and abstracts that suggested significant application were read in entirety to determine if the necessary data were available (i.e. lung lesion estimates and feed performance) and that the data reflected the desired population.

*Model assumptions*

The model assumed that both cattle with and without lung lesions were commingled within the same pen. Additionally, all cattle were sold on a live-weight basis; therefore, all cattle (independent of lung lesion status) within the pen were marketed at the same time. The model was performed on pen capacities that reflect typical US feedlot pen sizes.[4,55,57]

The model assumed that cattle with lung lesions in each pen were at an increased risk of BRD morbidity compared to cattle without lung lesions as evaluated at slaughter (Table 1).[8,9,21,34,38,43] To increase the conservative nature of the model and given the lack of empirical data, all cattle in the pen were modeled to exhibit the same risk of mortality regardless of lung lesion status.[4,5,26] Likewise, given the lack of peer-reviewed data evaluating feed intake among cattle with and without lung lesions, it was assumed that this parameter would be the same between cohorts, despite an increase in BRD risk among cattle with lung lesions; Table 1.[7,11,17,23,27,29,46,47] However, cattle with lung lesions were modeled to possess a reduced ADG compared to cattle without lung lesions in each pen (Table 1).[8,21,34,43,56] The morbidity and ADG distributions were constructed using data that was exclusive to cattle in 1 cohort or the other (i.e., with and without lung lesions). This was necessary for the analysis as estimates for cattle with lung lesions must be differentiated from those of cattle without lung lesions. Therefore, previously reported cumulative estimates (i.e. encompassing populations of cattle with and without lung lesions in the same estimates) for morbidity and ADG parameters (e.g. pen estimates) were not used in this analysis because they did not discern between the 2 cohorts.

Each theoretical pen of cattle was assumed to be marketed on a live-weight basis. The distribution around the selected point estimate ($1.19/lb or 0.45 kg; accessed on 31 March, 2016[15]) was calculated based upon a historical 9% spread separating the minimum and maximum estimates from the point estimate (Table 1).[2]

*Fitting probability distributions to observed data*

As expected, variability was observed across accepted studies for all stochastic parameters listed in Table 1. Given the relatively small number of data points (i.e., point estimate displayed in each reference; Table 1), non-parametric data distributions were fitted based upon their discrete or continuous classification.[49] Where applicable (i.e., ≥ 5 data points; a setting put in place by the risk-analysis software[c]), a best-fit assessment was performed by way of the Bayesian Information Criterion. In cases where < 5 data points (i.e., publications) were observed, the non-parametric distribution was generated based on subjective assessment of the available data.[49] These distribution estimations are further defined in Table 1.

With respect to percentage or proportion variables (e.g. lung lesion prevalence), Beta distributions were implemented

**Table 2.** Tabulated description of model flow to estimate the NET economic difference (per hd) between fed calves with and without lung lesions at slaughter.

**Node 1:** Estimation of lung lesion prevalence within a pen/lot of feedlot cattle

| Cell label | Variable | Parameter | Calculation |
|---|---|---|---|
| 1A | Pen size (number of total head) | Stochastic[a] | NA |
| 1B | Prevalence of lung lesions at slaughter | Stochastic | NA |
| 1C | No. of calves in the pen/lot with lung lesions at slaughter | Calculation | Roundup (1A*1B) |

**Node 2:** Estimation of the Cost of Gain (COG)

| Cohort | | | | | | | |
|---|---|---|---|---|---|---|---|
| Calves in pen with lung lesions at slaughter | | | | Calves in the pen without lung lesions at slaughter | | | |
| Cell label | Variable | Parameter | Calculation | Cell label | Variable | Parameter | **Calculation** |
| 2A | Number of calves | Calculation | 1C | 2B | Number of calves | Calculation | 1A-1C |
| 2C | Average purchase weight (lb) | Stochastic | NA | 2D | Average purchase weight (lb) | Calculation | 2C |
| 2E | Feeder calf market price (per cwt) | Stochastic | NA | 2F | Feeder calf market price (per cwt) | Calculation | 2E |
| 2G | Purchase price ($/lb) | Stochastic | NA | 2H | Purchase price ($/lb) | Calculation | 2G |
| 2I | Total purchase price ($) | Calculation | (2C*2G)*2A | 2J | Total purchase price ($) | Calculation | (2D*2H)*2B |
| 2K | Projected ADG/hd/day (lb) | Stochastic | NA | 2L | Projected ADG/hd/day (lb) | Calculation | 2K |
| 2M | Projected finish weight (lb) | Stochastic | NA | 2N | Projected finish weight (lb) | Calculation | 2M |
| 2O | Projected # of days in the feedlot | Calculation | roundup(2M-2C)/2K | 2P | Projected # of days in the feedlot | Calculation | 2O |
| 2Q | Feed cost/ton (DM basis) | Stochastic | NA | 2R | Feed cost/ton (DM basis) | Calculation | 2Q |
| 2S | Interest rate on capital to purchase calves | Stochastic | NA | 2T | Interest rate on capital to purchase calves | Calculation | 2S |
| 2U | Monthly payment (per head) | Calculation | PMT(2S/12,(2O/365)*12,(-2C)*2G,0,0) | 2V | Monthly payment (per head) | Calculation | 2U |
| 2W | Cost of interest (per head) | Calculation | ((2U*((2O/365)*12))-(2C*2G))/2O | 2X | Cost of interest (per head) | Calculation | 2W |
| 2Y | Freight distance to feedlot (miles) | Stochastic | NA | | | | |
| 2Z | Freight cost ($/per mile) | Stochastic | NA | | | | |

**Node 2:** Estimation of the Cost of Gain (COG) – **CONTINUED**

| Cohort | | | | | | | |
|---|---|---|---|---|---|---|---|
| Calves in pen with lung lesions at slaughter | | | | Calves in the pen without lung lesions at slaughter | | | |
| Cell label | Variable | Parameter | Calculation | Cell label | Variable | Parameter | Calculation |
| 2AA | Number of pot loads[b] | Calculation | (1A*2C)/50000 | | | | |
| 2AB | Freight cost (per pen) | Calculation | (2Y*2Z)*2AA | | | | |
| 2AC | Freight (per head) | Calculation | 2AB/1A | | | | |
| 2AD | Freight cost/hd | Calculation | 2AC/2O | 2AE | Freight cost/hd | Calculation | 2AD |
| 2AF | Overall mortality (%) | Stochastic | NA | 2AG | Overall mortality (%) | Calculation | 2AF |
| 2AH | Death loss cost/hd/day | Calculation | (2AF*2C)*2G)/2O | 2AI | Death loss cost/hd/day | Calculation | 2AH |
| 2AJ | Processing costs/head (at arrival) | Stochastic | NA | 2AK | Processing costs/head (at arrival) | Calculation | 2AJ |
| 2AL | Processing costs/hd | Calculation | 2AJ | 2AM | Processing costs/hd | Calculation | 2AL |
| 2AN | Increase in morbidity risk (%) | Stochastic | NA | | | | |
| 2AO | BRD morbidity (%) | Calculation | 2AP+(2AP*2AN) | 2AP | BRD morbidity (%) | Stochastic | NA |
| 2AQ | Number of morbid cattle | Calculation | roundup(2AO*2A,0) | 2AR | Number of morbid cattle | Calculation | roundup(2AR*2B,0) |
| 2AS | BRD treatment costs/sick calf | Stochastic | NA | 2AT | BRD treatment costs/sick calf | Calculation | 2AS |
| 2AU | Morbidity costs/hd | Calculation | (2AS*2AQ)/2A | 2AV | Morbidity costs/hd | Calculation | (2AT*2AR)/2B |
| 2AW | Beef check-off costs/hd | Static | NA | 2AX | Beef check-off costs/hd | Calculation | 2AW |
| 2AY | Yardage costs/hd | Stochastic | NA | 2AZ | Yardage costs/hd | Calculation | 2AY |
| 2BA | Operating interest costs/hd | Calculation | 0.02 * 2O | 2BB | Operating interest costs/hd | Calculation | 2BA |
| 2BC | Loss of feed efficiency due to lung lesions | NA | Assume to be 0 | | | | |
| 2BD | Loss of ADG due to Lung lesions (lb) | Stochastic | NA | | | | |

**Node 2:** Estimation of the Cost of Gain (COG) – **CONTINUED**

| Cohort | | | | | | | |
|---|---|---|---|---|---|---|---|
| Calves in pen with lung lesions at slaughter | | | | Calves in the pen without lung lesions at slaughter | | | |
| Cell label | Variable | Parameter | Calculation | Cell label | Variable | Parameter | Calculation |
| 2BE | Average daily gain (lb) | Calculation | 2BF-2BD | 2BF | Average daily gain (lb) | Stochastic | NA |
| 2BG | DMI (lb/hd/day) | Calculation | 2BH | 2BH | DMI (lb/hd/day) | Stochastic | NA |
| Overall Cost of Gain estimates | | | | | | | |
| 2BI | Non-feed cost/hd ($) | Calculation | ((Sum(2W,2AD,2AH,2AL,2AU,2AW,2AY,2BA,) | 2BJ | Non-feed cost/hd ($) | Calculation | ((Sum(2X,2AE,2AI,2AM,2AV,2AX,2AZ,2BB,) |
| 2BK | Feed cost/hd ($) | Calculation | ((2BG*2O)/2000)*2Q | 2BL | Feed cost/hd ($) | Calculation | ((2BH*2P)/2000)*2R |
| 2BM | Total Cost of Gain (per hd) | Calculation | 2BI+2BK | 2BN | Total cost of gain (per hd) | Calculation | 2BJ+2BL |
| 2BO | Total cost of gain | Calculation | 2BM*(2A-roundup(2A*2AF)) | 2BP | Total cost of gain | Calculation | 2BN*(2B-roundup(2B*2AG)) |

**Node 3:** Estimating market price

| Calves in the pen/lot with lung lesions at slaughter | | | | Calves in the pen/lot without lung lesions at slaughter | | | |
|---|---|---|---|---|---|---|---|
| Cell label | Variable | Parameter | Calculation | Cell label | Variable | Parameter | Calculation |
| 3A | Number of fed cattle | Calculation | 2A-(roundup(2A*2AF,0)) | 3B | Number of fed cattle | Calculation | 2B-(roundup(2B*2AG,0)) |
| 3C | Expected sale weight (lb) | Calculation | 2C+(2O*2BE) | 3D | Expected sale weight (lb) | Calculation | 2D+(2P*2BF) |
| 3E | Market price/lb of fed cattle | Stochastic | NA | 3F | Market price/lb of fed cattle | Calculation | 3E |
| 3G | Total dollars GROSS/pen | Calculation | (3A*3C)*3E | 3H | Total dollars GROSS/pen | Calculation | (3B*3D)*3F |
| 3I | Total dollars GROSS/hd | Calculation | (3G/3A) | 3J | Total dollars GROSS/hd | Calculation | (3H/3B) |
| 3K | Total COG/pen | Calculation | 2BO | 3L | Total COG/pen | Calculation | 2BP |
| 3M | Total COG/hd | Calculation | (3K/3A)+(2I/2A) | 3N | Total COG/hd | Calculation | (3L/3B)+(2J/2B) |
| 3O | Difference in total GROSS income/hd | | Calculation | | | | 3I-3J |
| 3P | Difference in total NET/income/hd | | Calculation | | | | 3O-(3M-3N) |

[a]Stochastic parameters refer to distributions outlined in Table 1 for each respective variable.
[b]This calculation assumes a 50,000 lb load limit.

in order to allocate more statistical weight to larger studies. The Beta distribution is summarized by Beta(s+1, n-s+1) where 'n' equals the sample size and 's' reflects the number of observations of interest (e.g., number of calves with lung lesions, number of dead calves). In construction of Beta distributions (Table 1), although it is recognized that large studies do garner greater weight, there are additional factors that likely increase the variability of the parameter, such as estimation of lung lesions using different scoring methods among studies or number of available studies. Therefore, in order to provide a more conservative estimate, a divisional factor was assigned to the initial Beta distribution in order to increase the variation within the distribution while allowing the point estimate to remain the same (Table 1). The magnitude of each divisional factor was subjectively chosen based upon the number of peer-reviewed sources of available data (i.e. a larger divisional factor was implemented if the number of data sources was small) and to reflect the range of values reported therein.

For all distributions, truncation limits were implemented to avoid parameter values outside the realm of the chosen distributions, thereby eliminating the risk of nonsensical values (Table 1). These limits were selected based upon the literature values found for each respective parameter. For example, the supporting literature for lung lesion prevalence ranged from 3.3%[34] to 87%,[9] respectively. Therefore, truncation limits were set at these values to ensure that estimates outside of this range (i.e. estimates not supported by data) would not enter the model.

*Application of the model*

The model was evaluated by a commercial simulation program;[c] an add-in for a commercial software package.[d] The model simulation was composed of 10,000 iterations using a fixed number random seed of 1 and utilizing Monte Carlo sampling techniques.

A sensitivity analysis was performed to reflect the magnitude of variation that each stochastic parameter dictated on the outcome of each model. In general, parameters with greater correlation coefficient values (positive or negative) exert a larger influence on the outcome of the model compared to parameters with lesser values.

*Model validation*

The model was validated using previously described techniques.[49] Briefly, the model calculations and parameter units (e.g. percentages) were audited and followed downstream to ensure accurate outcomes. Upon running the model, the array of scenarios was evaluated to ensure that all iterations ran and that the distributions of the outcomes generated from the iterations reflect the distributions assigned to the respective parameters. Lastly, scatter plots were evaluated between input variables and the final outcome variable to ensure model validity.

## Results

The overall objective of this model was to estimate the relative economic impact on cattle with lung lesions in the feedlot when compared to cattle without lung lesions. Based upon this stochastic model, the relative economic value of cattle with lung lesions is almost always less compared to cattle without lung lesions at the end of the feeding period (Table 3). Net income analysis (Table 3) indicates that cattle with lung lesions lose, on average, $38.69 (90% probability interval [PI]: $12.28 to $79.32) compared to cattle without lung lesions.

The results of the sensitivity analysis are displayed in Table 4. Positive correlation coefficients suggest that as the parameter of interest increases, the divergence in the relative economic value between cattle with and without lung lesions is reduced. Conversely, a negative correlation coefficient suggests that as the parameter of interest increases, the difference in value between the 2 cohorts is increased. With regard to net income (Table 4), this analysis suggests that the loss of ADG due to lung lesions, average purchase weight, projected finish weight, and projected ADG were strong contributors to the variation in the relative economic value between the 2 cohorts of cattle.

## Discussion

Despite wide-scaled efforts to minimize the negative effects of BRD, this disease syndrome continues to impact

**Table 3.** Distribution of net economic value estimates (per hd) among pens of feedlot cattle with and without lung lesions. The estimates reflect a direct comparison between cattle with lung lesions to cattle without lung lesions. Estimates with parentheses indicate negative monetary values (i.e., the gross value of cattle with lung lesions is less than cattle without lung lesions).

| | Descriptive statistics* | Difference of cattle with lung lesions compared to cattle without lung lesions |
|---|---|---|
| Gross income | Max | $0.42 |
| | 95% | ($12.28) |
| | 75% | ($23.11) |
| | Mean | ($38.69) |
| | Median | ($34.65) |
| | Mode | ($21.20) |
| | 25% | ($49.88) |
| | 5% | ($79.32) |
| | Min | ($162.52) |

*Percentile values (%) indicate the percentage of data at or below that specific point. For example, cattle with lung lesions are expected to lose ≥ $12.28 95% of the time (i.e., the 95th percentile) compared to cattle without lung lesions. Conversely, cattle with lung lesions are expected to lose ≥ $79.32 only 5% of the time (i.e., the 5th percentile) compared to cattle without lung lesions.

**Table 4.** Below is the sensitivity analysis that reflects the parameters that impact the difference in net economic value between cattle with and without lung lesions. Positive correlation coefficients suggest that as the parameter of interest increases, the divergence in the relative economic value between cattle with and without lung lesions is reduced. Conversely, a negative correlation coefficient suggests that as the parameter of interest increases, the difference in value between the two cohorts is increased.

| Rank | Parameter | Correlation coefficient |
|---|---|---|
| 1 | Loss of ADG due to lung lesions | -0.66 |
| 2 | Average purchase weight (lb) | 0.47 |
| 3 | Projected finish weight | -0.40 |
| 4 | Projected ADG/hd/day | 0.37 |
| 5 | Market price of fed cattle | -0.06 |

multiple phases of beef and dairy production. In the feedlot industry, previous studies have observed that large proportions of cattle, with and without prior BRD diagnoses and therapy, possess lung lesions (indicative of past or present BRD) at slaughter.[8,9,21,34,35,43,56,30] Given that cattle have a very small volume of lung tissue relative to their respective body size (e.g. as compared to a horse of the same body weight), it is reasonable to suggest that cattle are very sensitive to a reduction in functional lung tissue. Therefore, it is not surprising that if cattle live through the BRD insult(s) the potential loss of pulmonary function could translate into a reduction in weight gain.

Given the magnitude of data supporting an association between the presence of lung lesions and a reduction in ADG, the level of variability in ADG reduction across studies (Table 1) brings into question its potential economic impact. The findings generated in this study indicate that cattle with lung lesions at slaughter are of less relative economic value compared to penmates without lung lesions (Table 4). Based on the assumptions of this model, cattle with lung lesions average a $38.69 loss/hd compared to pen mates without lung lesions, independent of the other parameters evaluated in this model.

The results in the sensitivity analysis provide insight into the parameters that influence the model outcomes. Not surprising given the background literature, the sensitivity analysis conveyed the relatively large influence of ADG reduction among cattle with lung lesions (Table 4). The negative correlation of ADG to the outcome (i.e. the difference in net earning between cattle with and without lung lesions) suggests that as the loss in ADG increases among cattle with lung lesions (relative to cattle without lung lesions) the economic value in this cohort, relative to cattle without lung lesions, is reduced. Although expected, these findings agree with observations in prior studies which displayed a reduction in ADG among cohorts of cattle with lung lesions compared to those without lung lesions.[8,21,34,35,43,56] Among the remaining parameters in Table 4, positive correlations were observed for average purchase weight and projected ADG. These findings suggest that as either or both parameters are increased, the disparity in value between the 2 cohorts is reduced. This can be attributed to a reduction in the duration of the feeding period (average purchase weight) and an improvement in feed performance (projected ADG). Both parameters would be expected to have a positive impact on overall value, thereby reducing the financial gap between cohorts. Similar findings have been observed in prior studies among general feedlot populations, such as commingled cohorts.[3,12] Nonetheless, based upon the assumptions built into this model, cattle with lung lesions are almost always of less economic value compared to cattle without lung lesions (Table 3). Projected finish weight and market price of fed cattle were observed to be negatively correlated (Table 4), indicating that as these parameters increase the difference in economic value is increased; therefore, as cattle get heavier and of greater value, the ability to reduce the negative impact of lung lesions becomes of greater importance to the producer.

The observed average loss of $38.69 between cattle with and without lung lesions may be conservative due to the assumptions implemented within the model. Given the method in which the majority of prior lung lesions prevalence estimates have been reported, the current model categorized cattle in only 2 categories: cattle with lung lesions and cattle without lung lesions. This may underestimate the impact of lung pathology, as it is plausible that the magnitude of lung pathology may be directly correlated with the degree of negative economic impact. Tenant et al categorized the lungs of calves at slaughter into 6 categories; as the magnitude of lung pathology increased, the value per head declined.[42] Interestingly, economically (and statistically) significant differences were not observed until lung pathology exceeded 5%, suggesting that cattle can withstand minor lung pathology without impact on performance. However, once lung pathology exceeded 5%, economic value of the animal declined. Collectively, Tenant et al reported a difference of $122.16/hd between calves with normal lungs and calves with lung consolidation exceeding 50%.[42] Although rare (i.e., < 5% of the time based on the assumptions of this model), this value was observed within the probability distribution of the outcome (Table 3).

Prior studies have observed history of BRD treatment among cattle with and without lung lesions.[8,10,21,34,43] Therefore, lung lesion status is not an accurate assessment of prior BRD treatment. In the field, it may be difficult to determine if the presence of lung lesions is attributed to the inability to accurately diagnosis BRD, suboptimal efficacy associated with current preventive and treatment modalities, or a combination of the 2 variables. Cattle, as a species, are highly adept at concealing the signs of disease. Therefore, once clinical BRD is observed, lung pathology may already be present.[9,24,33,51] Current BRD diagnostic regimens typically consist of a visual assessment of the animal and a rectal temperature that meets a specific threshold. However, as outlined above, this approach has previously been observed to be highly inaccurate when compared to cattle with lung lesions.[8,21,43,56] Conversely, although the efficacy of antimicrobials is critically evaluated prior to approval, previous studies have observed lung lesions among cattle with history of BRD therapy. These findings are likely due to inaccurate (i.e., late) BRD diagnoses and the timing of drug administration. These findings substantiate the need for improving BRD diagnostic capabilities while expanding the available tools to manage BRD.

Despite the difference observed in this model regarding the relative economic value between cattle with and without lung lesions, it should be noted that these findings are only representative of feedlots that parallel the multiple assumptions built into the model. Therefore, extrapolating these findings to feedlots that implement different management parameters and marketing goals (e.g. grid-markets, pen-sorting prior to slaughter), or to different segments within the beef production chain (e.g. the stocker segment of the beef industry), should be performed with caution. Additionally, these data should also be interpreted in light of the probability distributions built into the model (Table 1). In other words, feedlots implementing production parameters outside the bounds of these probability distributions may not be able to extrapolate these current results to their own production system. However, given the conservative nature of the model and the distributions used, the modeled estimates may actually underestimate the true overall cost of lung lesions (on a per-head basis) among cattle that live to slaughter.

The findings from this analysis suggest that lung lesions are very costly to the feedlot segment of the beef industry. As described above, lung lesions are the consequence of BRD and have been observed in cattle both with and without history of BRD diagnosis and therapy. This would suggest that implementation of sound preventive practices, diagnosing BRD earlier in the disease process, and administering efficacious therapy in a timely fashion would lessen the incidence of BRD and subsequently reduce the risk of lung lesion development. However, because of the extreme variability in the disease process and the inherent ability of cattle to disguise clinical signs, current BRD diagnostic practices have been shown to be far from optimal.[53] Furthermore, current BRD therapy and preventive practices have not curtailed the overall incidence of BRD over time,[28] and ancillary BRD therapy has not shown consistent efficacy in clinical trials.[18] Therefore, more work is needed to expand our toolbox in order to effectively combat and control the negative effects of BRD.

## Conclusion

Based upon the assumption of this model, cattle with lung lesions lose, on average, \$38.69 (90% PI: \$12.28 to \$79.32) compared to cattle without lung lesions. The reduction in ADG among cattle with lung lesions was shown to be a substantial driver in these outcomes, which supports the findings from prior studies. Improved BRD diagnostic and therapeutic modalities are necessary in order to reduce the prevalence of cattle with lung lesions and the subsequent negative economic impact to the feedlot industry.

## Endnotes

[a]Reinhardt CD. Feedlot Extension Specialist; Kansas State University. Personal communication. 10 May, 2013.
[b]Good K. Senior Analyst-Fed Cattle Market Specialist; Cattle-fax; Personal communication; 18 April, 2014.
[c]@Risk©, Professional edition, Version 6.1.2, Palisade Corp., Ithaca, NY
[d]Microsoft® Excel 2010 (© 1985-2010 Microsoft Corp., Redmond, WA)

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